Mucool Test Area

Cryo-system Design

BD/Cryo Internal Review

Part V

A look at the Hydrogen Proposal

Ch. Darve

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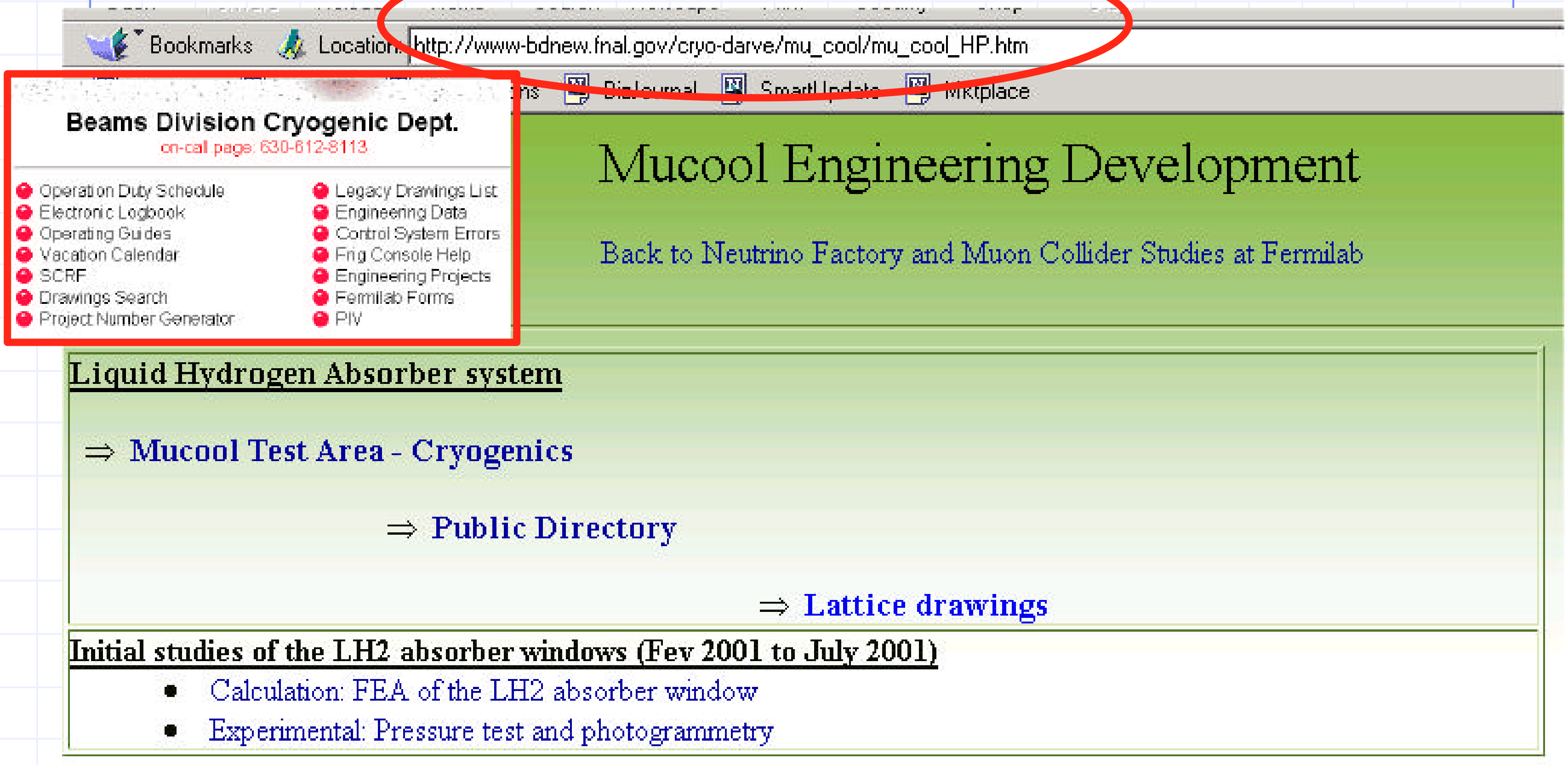
Part V – A look at the Hydrogen Proposal

Information located on web page



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Our main guidelines are expertise from previous LH_2 experiments, code/standard ASME, NEC (art 500) and Fermilab ES&H (5032), CGA…

Fermilab: " Guidelines for the Design, Fabrication, Testing, Installation and Operation of LH2 Targets – 20 May 1997" by Del Allspach et al.

NASA: " SAFETY STANDARD FOR HYDROGEN AND HYDROGEN SYSTEMS: Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation

Others LH_2 exp.: Reports from SAMPLE, E158, G0…

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The design of the MTA cryo-system permits us to create the Aborber Safety Review book-Ref ES&H:

5032.2: GUIDELINES FOR THE DESIGN, REVIEW AND APPROVAL OF LIQUIDCRYOGENIC TARGETS

The Target Safety Review book shall contain all of the required documents of Chapter 5032TA, including the following:

1. Structural calculations on all parts of the target
2. Venting calculations for the target
3. Venting calculations for the vacuum space
4. Venting calculations for the secondary containment
5. Complete drawings of the target, vacuum system and secondary containment
6. Instrument and valve summary
7. Interlock list
8. Operating procedures
9. Emergency procedures
10. Operational call-in list
11. Material certification data on part
12. FMEA, what-if analysis
13. Flow diagram
14. Testing results

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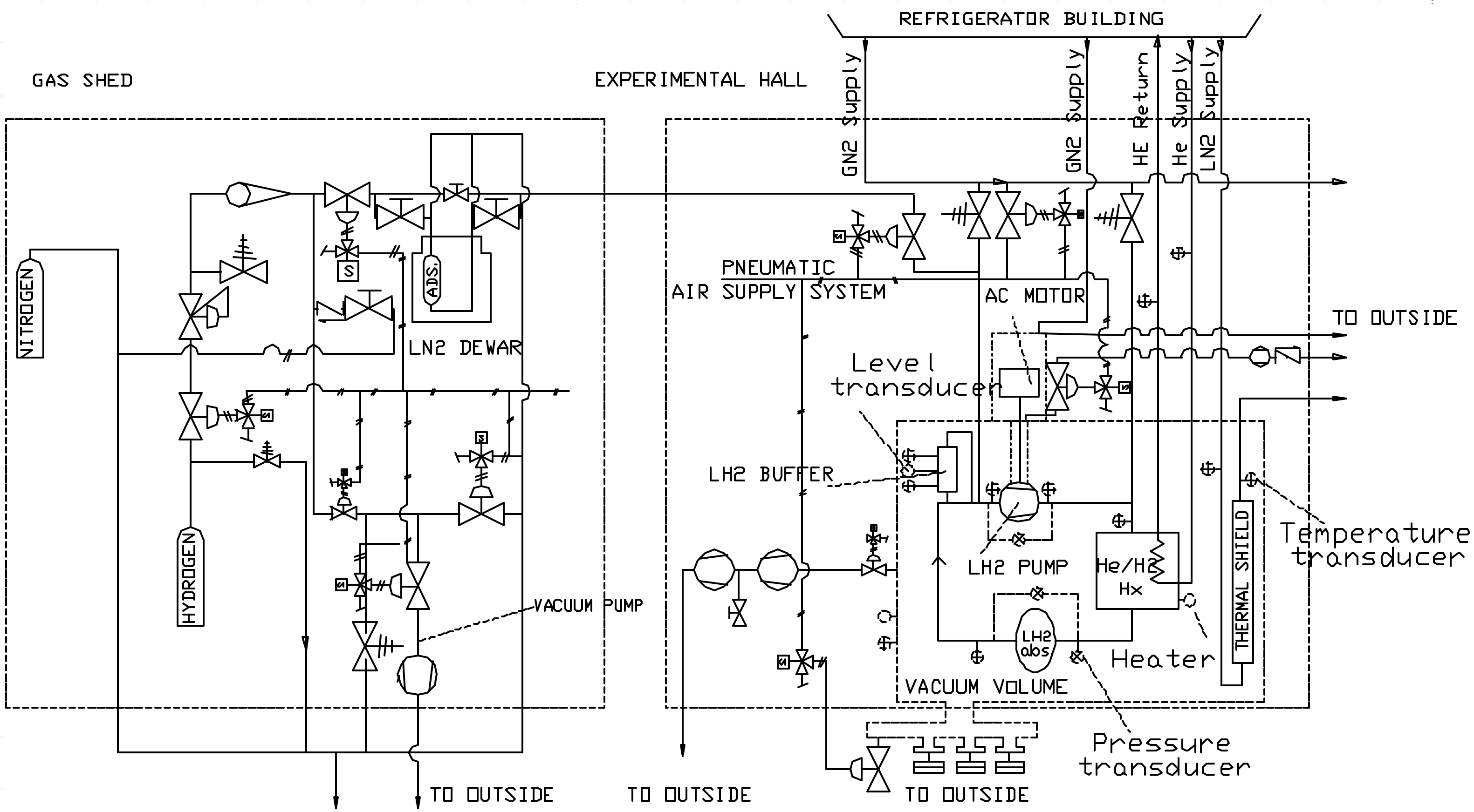
Process and Instrumentation Diagram



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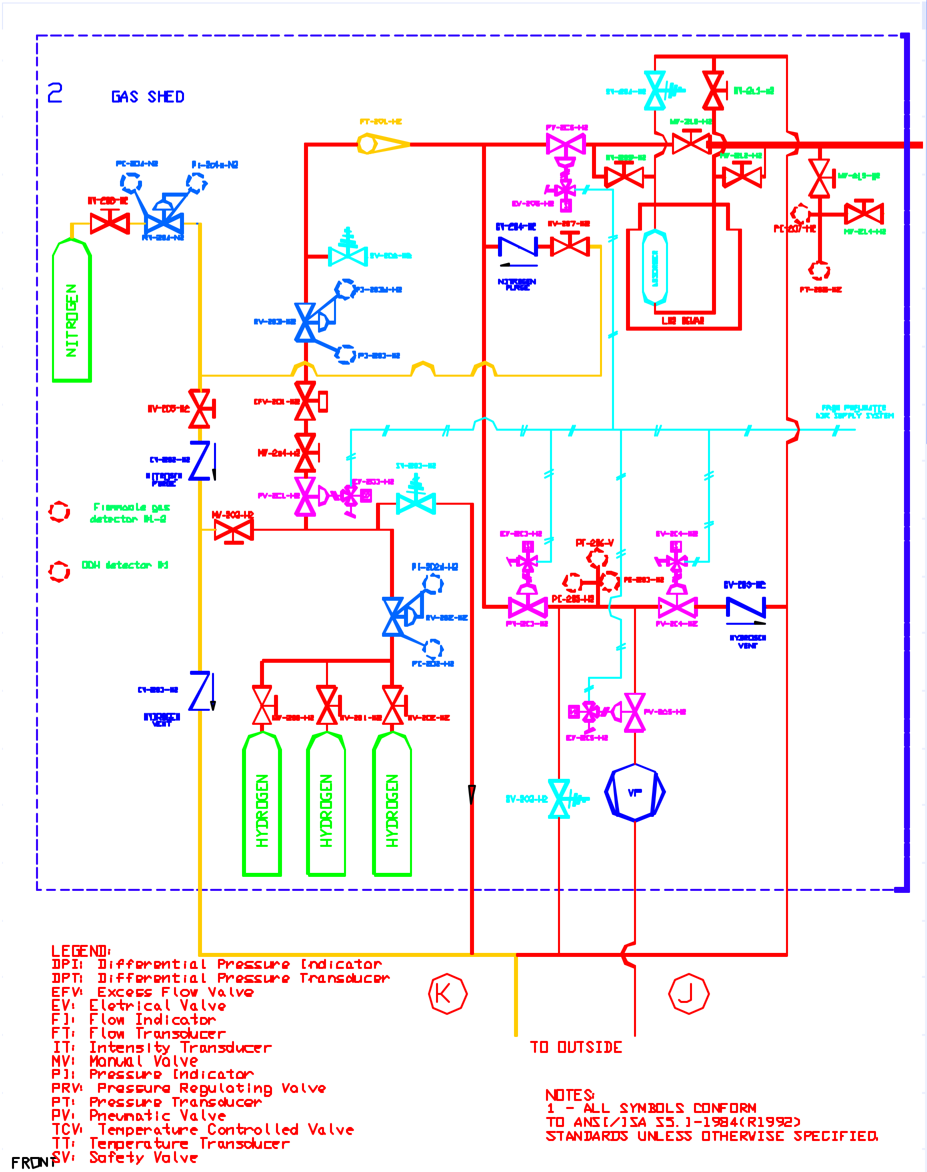
Equipment:

- Gas H2 bottle
- Gas N2 bottle
- O2 adsorber
- Vacuum pump
- Flam. Gas detector
- ODH detector
- Pneumatic air supply sys.

Instrumentation:

- Flowmeter Transducer
- Pressure Reg. Valve
- Safety Valve
- Manual Valve
- Excess flow Valve
- Pneumatic Valve
- Electrical Valve
- Check Valve
- Pressure Indicator
- Pressure Transducer



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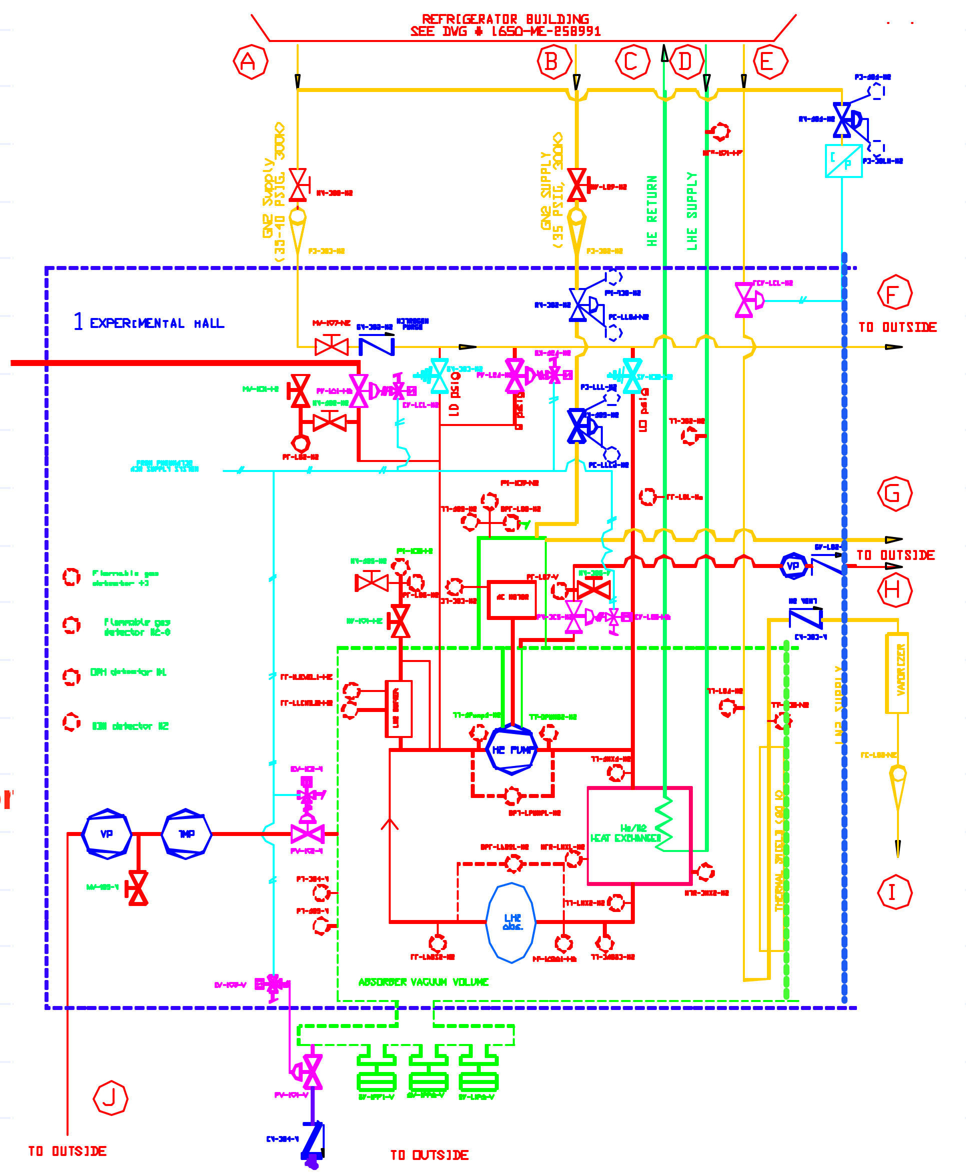
Equipment:

- Roughing Vacuum pump
- Turbo Molecular pump
- Gas He Supply/Return
- Gas N2 Supply/Return
- Liq. N2 Supply/Return
- Vaporizer
- Flam. Gas detector
- ODH detector
- Pneumatic air supply sys.

Instrumentation:

- Temperature Transducer
- Pres. Transducer and Indicator
- Flowmeter Indicator
- Heater
- Safety Valve
- Temperature Controlled Valve
- Pressure Reg. Valve
- Manual Valve
- Electro+ Pneumatic Valve
- Check Valve



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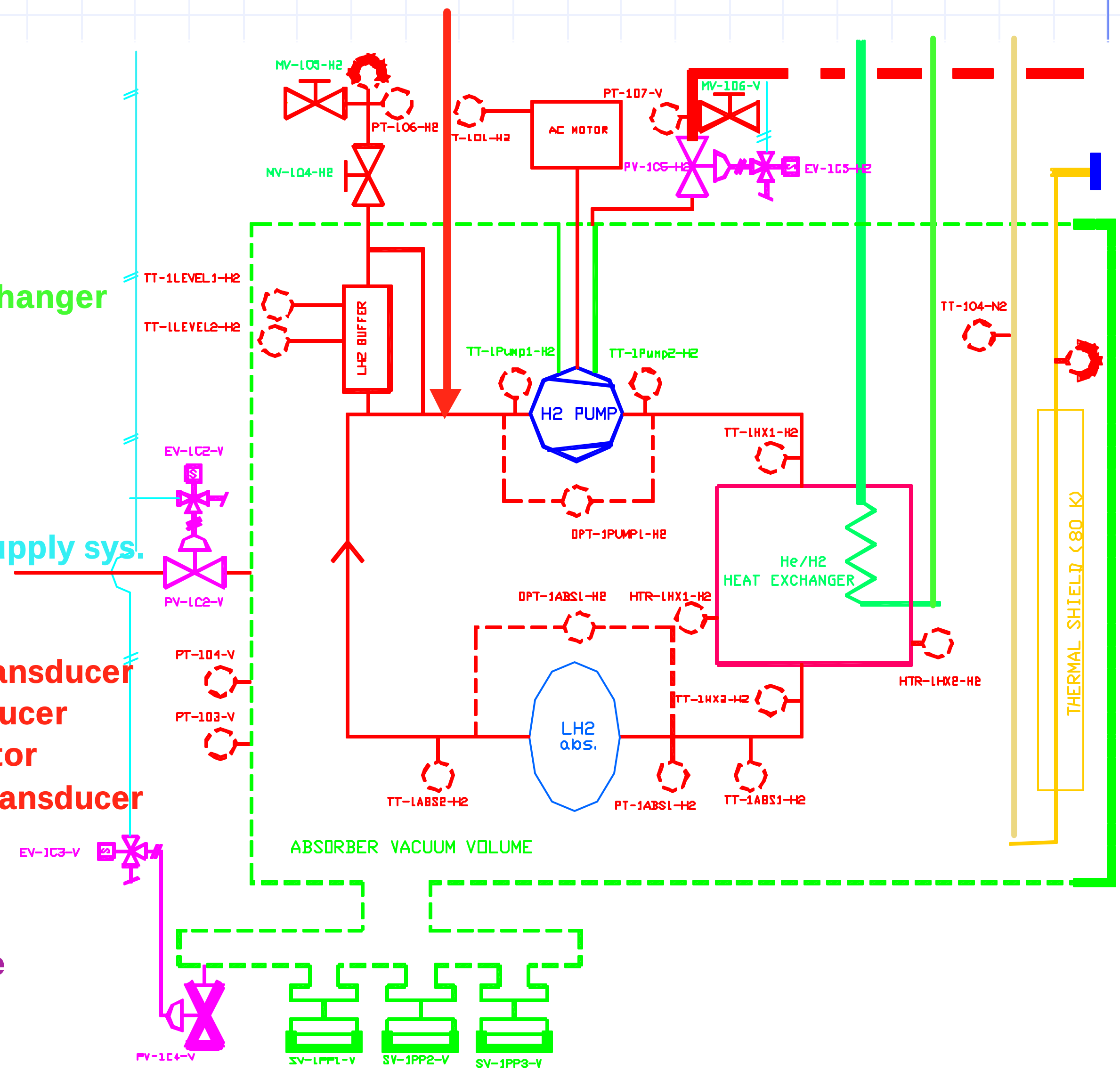
Equipment:

- Absorber
- He/H2 Heat Exchanger
- LH2 pump
- AC motor
- LH2 buffer
- Vacuum pump
- Thermal shield
- Pneumatic air supply sys.



Instrumentation:

- Temperature Transducer
- Pressure Transducer
- Pressure Indicator
- Diff. Pressure Transducer
- Heater
- Safety Valve
- Manual Valve
- Pneumatic Valve
- Electrical Valve
- Check Valve

Choice of instrumentation/equipment dictated by:

Equipment explosion proof (Class I, Div. I, Group B)

- ✓ If not possible, then the system must be intrinsically safe: provide safeguards (i.e. nitrogen barrier environment)
- ✓ Instrumentation compatible with Interlock system
- ✓ Redundancy of valves, purge systems and instrumentation
- ✓ Prevent air to enter the vacuum vessel (leak-tight)

Preferred set-up:

- Enclosed in a leak-tight vessel and purged with N_2
- Ceramic feedthoughs for electrical connections
- Weld is preferred to flange or other fitting if possible
- VCR fitting for union and piping connection
- Doubled-seal flange if risk O_2 penetrate via instrumentation cable
- Valve normally close (for space insulation dictated by interlock)
- Non magnetic material
- Radiation hardness: to withstand 0.11mS/hr (11mrem/hr)
- Output 4-20 mA signal to lower the risk of ignition

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Instrumentation list

Choice of instrumentation

Intrinsically safe: Mechanics

- Safety valve (SV):
  X 4 in gas shed: AGCO
  X 2 for LH2 loop: AGCO
  X 3 for insulation vacuum: FNAL design parallel plate

Explosion proof

- Pneumatic Valve (PV)
- Electrical Valve (EV)
  X 10 : Herion
  - To control the pressure in the loop, the insulation vacuum, the thermal shield temperature and the motor cooling

Explosion proof

- Excess Flow Valve (EFV)
  X1 :Swagelok

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Instrumentation list

Explosion proof

- Temperature Control Valve (TCV)
  x 1 : Badger meter
  - Make use of a I to P (Fairchild) for the pressure control

Intrinsically safe: Mechanics

- Manual Valve (MV)
  x 22: Swagelok
  - to add on the system

Intrinsically safe: Mechanics

- Check Valve (CV)
  x 8: Swagelok
  - Venting line and purge system

Intrinsically safe: Mechanics

- Regulator Valve (RV)
  X 6: Matheson tri-gas
  - Pressure from 2400 lbs gas cylinder to 17.6 psia Absorber cryoloop

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Instrumentation list

Intrinsically safe: Mechanics

- Pressure Indicator (PI)
  - X 12: Swagelok or Matheson tri-gas
    - check pressure along the loop, used for regulators

Explosion proof

- Pressure transducer (PT)
  - X 4: Barton
    - Pressure in LH2 loop: 0-100 psig, output: 4-20 mA
  - X 1: Leybold- Penning
    - Pressure in insulation vacuum: 0-10^{-8} torr
  - X 3: Leybold- Pirani
    - Pressure in insulation vacuum: 0-10^{-3} torr

Intrinsically safe: N_2 purge

Explosion proof

- Differential pressure transducer (DPT)
  - X 3: Barton
    - Pressure in LH2 loop: 0-30 psig, output: 4-20 mA

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Instrumentation list

- Temperature transducers

X 6: Lake shore Cernox: CX-1070-SD
  - Redundant System
  - Installed in insulation vacuum
    - Answer time ~ 0.01 sec
    - But delayed by impedance stainless steel

Intrinsically safe:
Electronics
Elec. connector

X 3: Lake shore Platinum: Pt100
  - Installed in insulation vacuum

Intrinsically safe:
Electronics
Elec. connector

X 4: VPT- Barton differential pressure (0-100 psig)
  - Answer time ~ 1 sec
  - Direct measurement of the flow pressure (no impedance)

Explosion proof

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Instrumentation list

- Heaters

  X 2: Acrolab

  - System redundant
  - Installed in insulation vacuum:

  => low risk of ignition

  => Use interlock on the insulation vacuum pressure

Intrinsically safe:
Electronics
Elec. connector

Or E158 Solution: 0.19 Ω/ft Nichrome wire, R=1 Ω wrapped around G7.

✓Minimum spark energies for ignition of H_2 in air is 0.017 mJ at 1 atm, 300 K
✓Lower pressure for ignition is ~1 psia (min abs. 0.02 psia // 1.4 mbar)

- ODH sensors x3
- Flammable Gas sensor x10

Supplied by Fermilab / FESS

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Instrumentation list

- Turbo Molecular Pump (TMP)
  X 1: Leybold
  - Nitrogen barrier environment and cooling
  - Installed in close vessel
  - Equipped w/ Gate valve
  - Inst. vac. (as per II D 5) with interlocks

Intrinsically safe: N_2 purge

- Roughing pump
  X 3: Leybold
  - Nitrogen barrier environment and cooling
  - Installed in close vessel

Intrinsically safe: N_2 purge

- 2HP motor (LH2 pump driver)
  X 1: Fermilab
  - needs to be cooled

Intrinsically safe: N_2 purge

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- All connector are leak tight: Ceramseal 10236-03-CF (rated for cryogenic temperature)

- Double-seal connectors of flange can be use for barrier.

- All monitors (TT,PT, LT, HTR) and controllers are installed inside a close rack at the proximity of the cryo-system (<15'). Hence N_2 purge requested (RT,5 psig).

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Absorber cryo-system monitoring and control

Valve	Function	Loop	Set point
EV-1C4-H2	LH2 Vent	PT-1ABS1-H2	1.2 atm
EV-1C1-H2	H2 input	TT-1LEVEL1_H2	80 %
IP-1C1-N2	N2 can	TT-105-N2	80 K
EV-1C2-V	Inst. Vac	PT-104-V	10^-5 torr
EV-1C5-H2	Pump Vac	DPT-108-N2 TT-1Pump2-H2	5 psid 1.2 atm
Motor speed	2 HP	PT-1ABS1-H2	1.2 atm
HRT-1HX1-H2	HX 500 W	TT-1ABS1-H2 Beam Control	17K TBD
HRT-1HX2-H2	HX 500 W	TT-1ABS1-H2 Beam Control	17K TBD

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What if analysis

- **Rupture of LH_2 loop**
  - **Sizing of relief sys. for LH_2 loop venting**
  - **Sizing of relief sys. for vacuum vessel venting**
  - **Interlocks**

- **Loss of vacuum vessel insulation vacuum**
  - **Interlocks**
  - **Boil-off rate**
  - **Pressure rate**
  - **Conduction though window wall**
  - **Convection heat transfer for surrounding gas**

- **Failure of LH_2 pump motor or LH_2 pump**
- **Failure of heater**
- **Failure of beam**
- **Failure of TMP**
- **Leak in N_2 purge system**
- **Solidification of LH_2**

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Interlock system and emergency conditions

- On insulation vacuum: degradation (II D 5: 50 micron Hg)
  - Beam off, pumps off..
- On the N_2 purge (TMP, motor, controller/monitor close rack)
  - Use 2 instrumentations w/ wrong set-point
  - Insulation valve and stop powered equipment
- On Heater on the HX = if pressure in insulation vacuum

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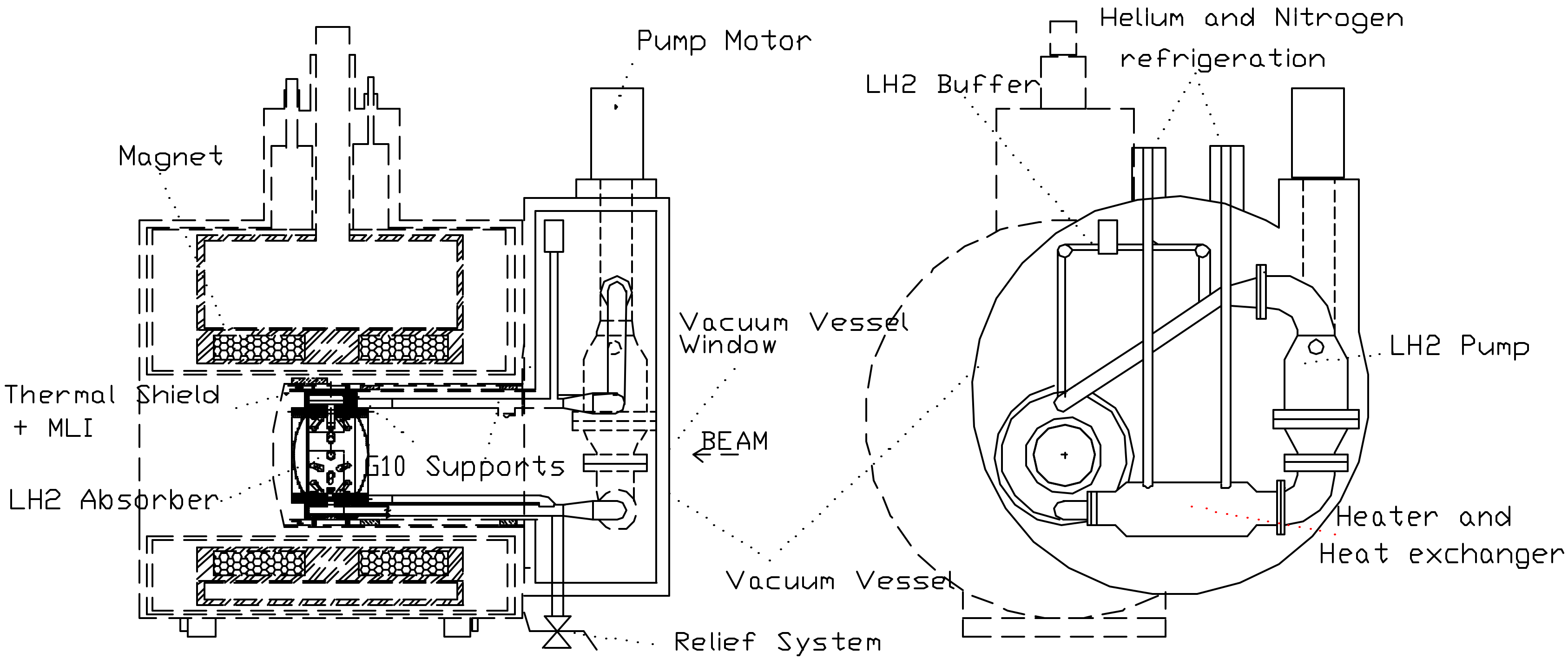
Cryo-system conceptual design



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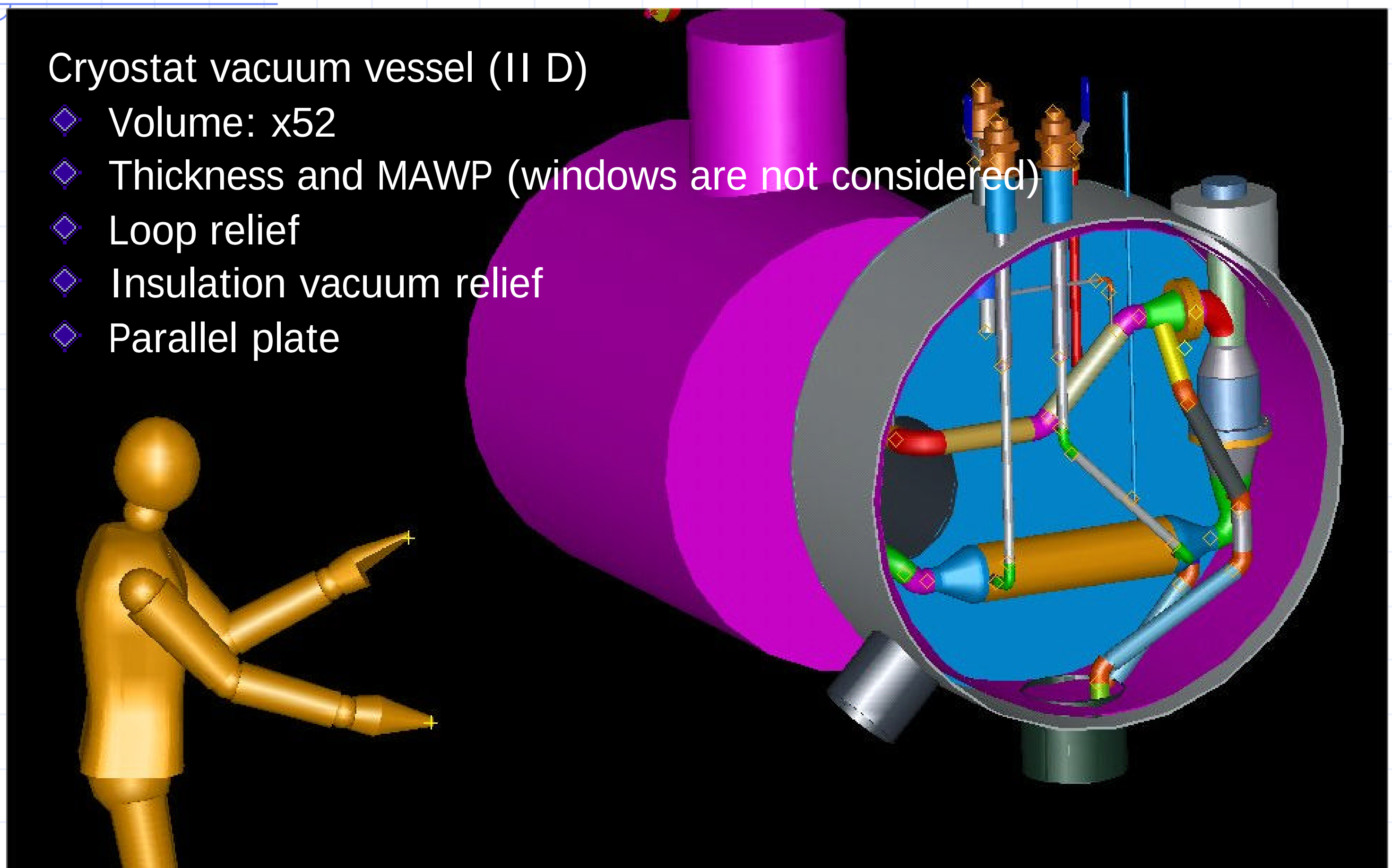
Cryo-system design

Cryostat vacuum vessel (II D)

- Volume: x52
- Thickness and MAWP (windows are not considered)
- Loop relief
- Insulation vacuum relief
- Parallel plate



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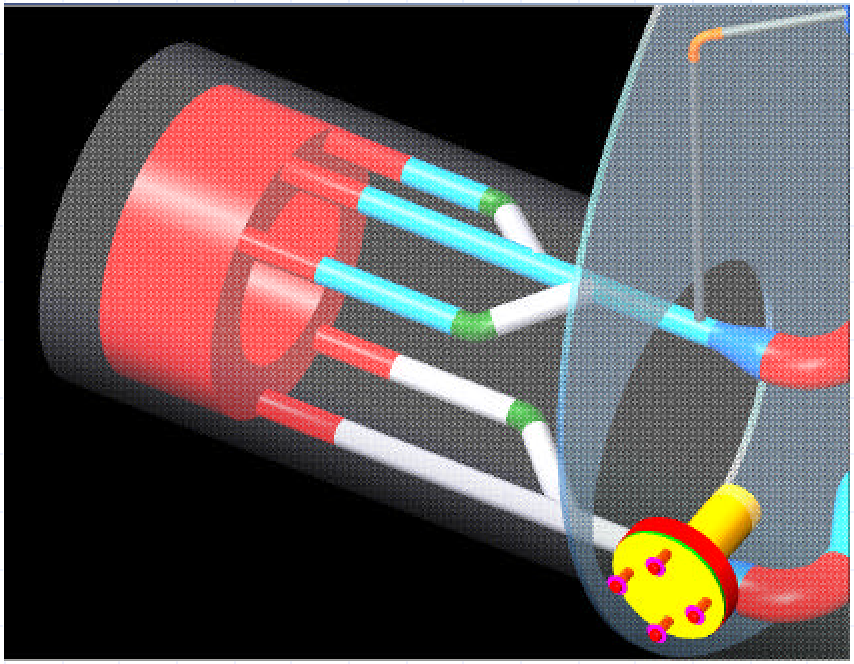
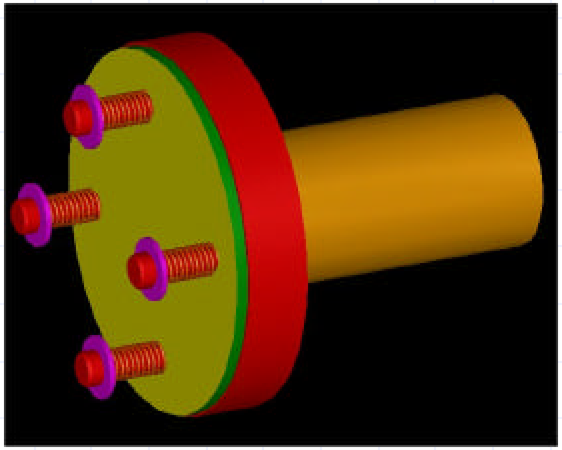
Cryo-system design

1 - Cryostat Set-up assembly:

- **Piping IPS1, IPS2 Sc5, Bimetallic transitions…**
- **Safety devices: Parallel plate, AGCO**





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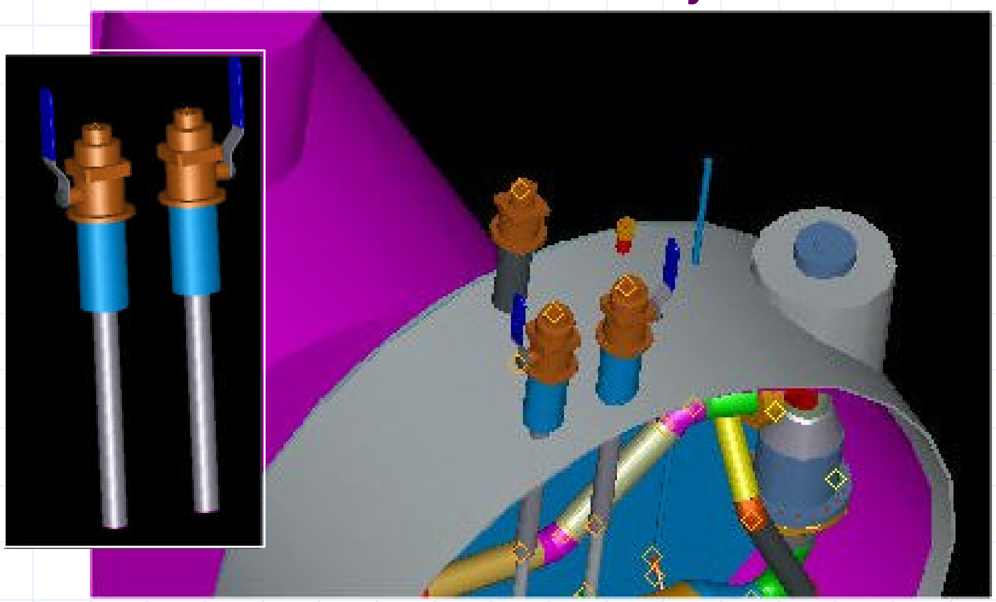
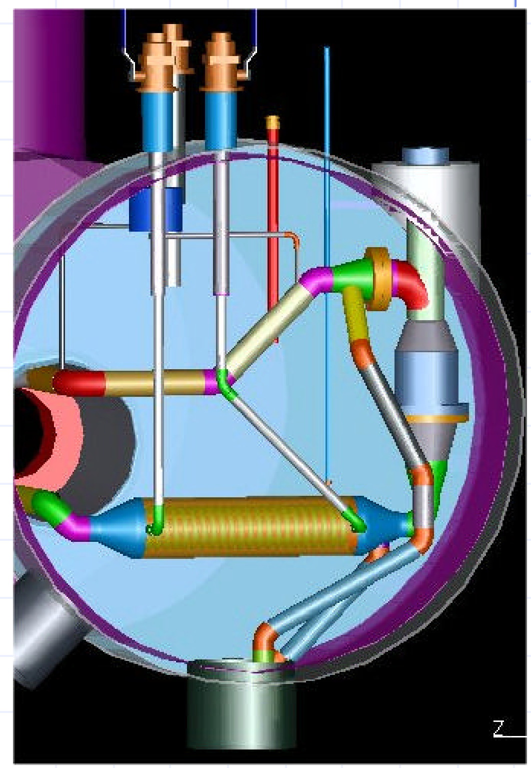
Cryo-system design

1 - Cryostat Set-up assembly:

- **Thermal + MLI,**
- **Vacuum vessel,**
- **Connection to pumping sys,**
- **Transfer lines and bayonets.**





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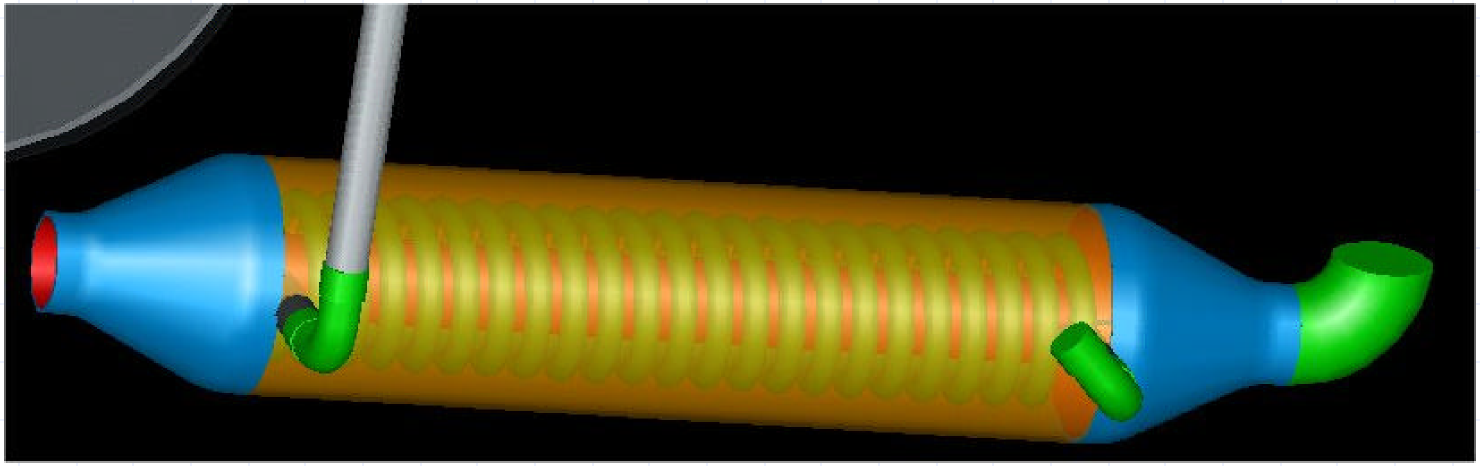
Cryo-system design

2- Heat exchanger assembly:

- **Copper coil,**
- **Outer shell,**
- **Diameter reduction,**
- **He inlet and outlet,**



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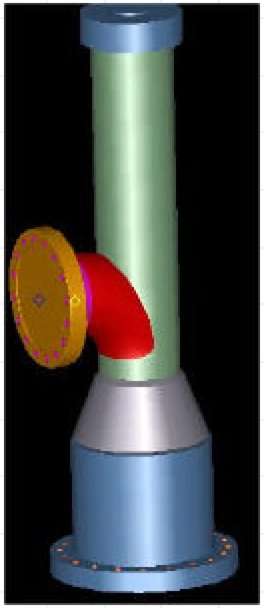
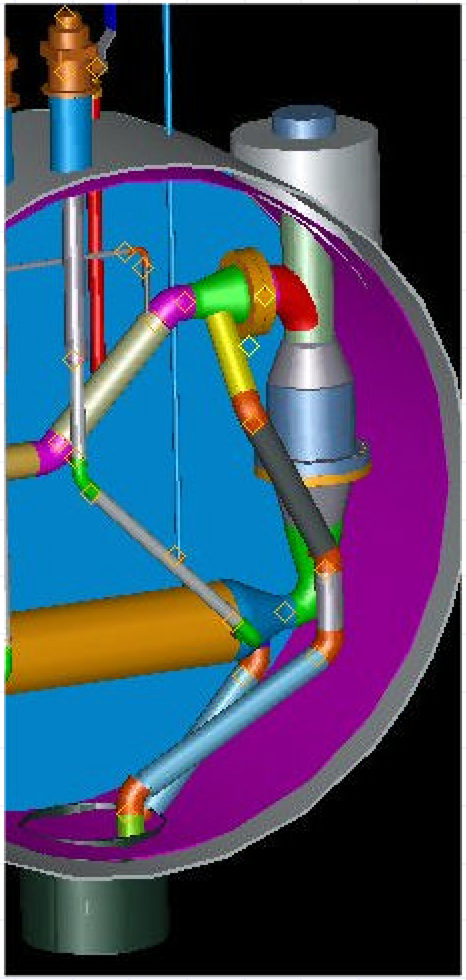
Cryo-system design

3- LH2 Pump assembly:

- **Pump torque transition,**
- **Motor outer shield,**
- **Cooling system,**
- **Pumping system of the outer shield,**
- **Relief valves piping.**





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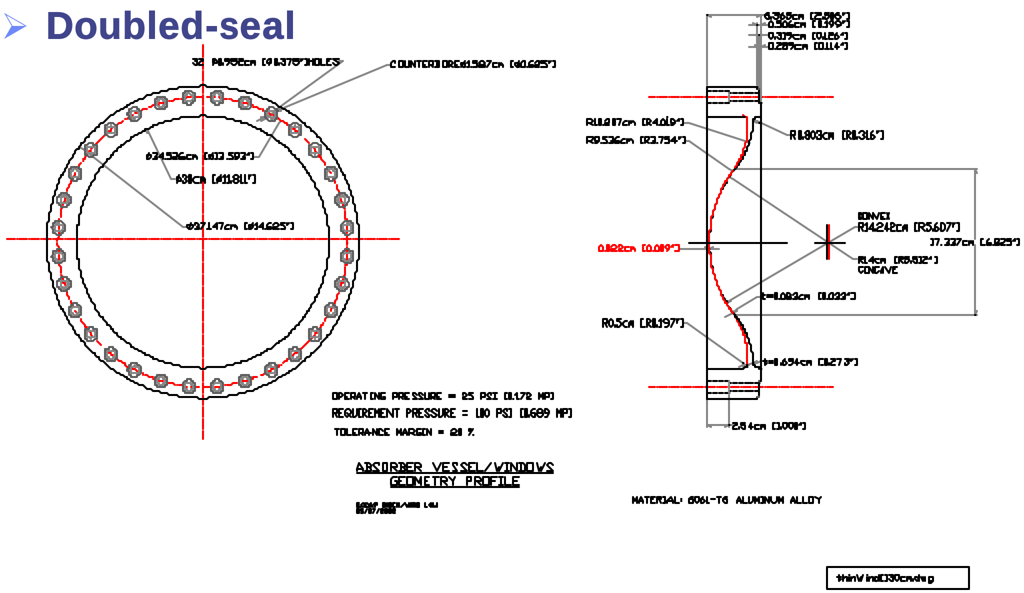
Cryo-system design

4- Absorber assembly:

Implement Ed Black / Wing Lau drawings with cryostat vacuum vessel windows, absorber

Design interface of the systems (flanges, piping)

- **Absorber manifolds**
- **Windows in the loop**
- **Doubled-seal**



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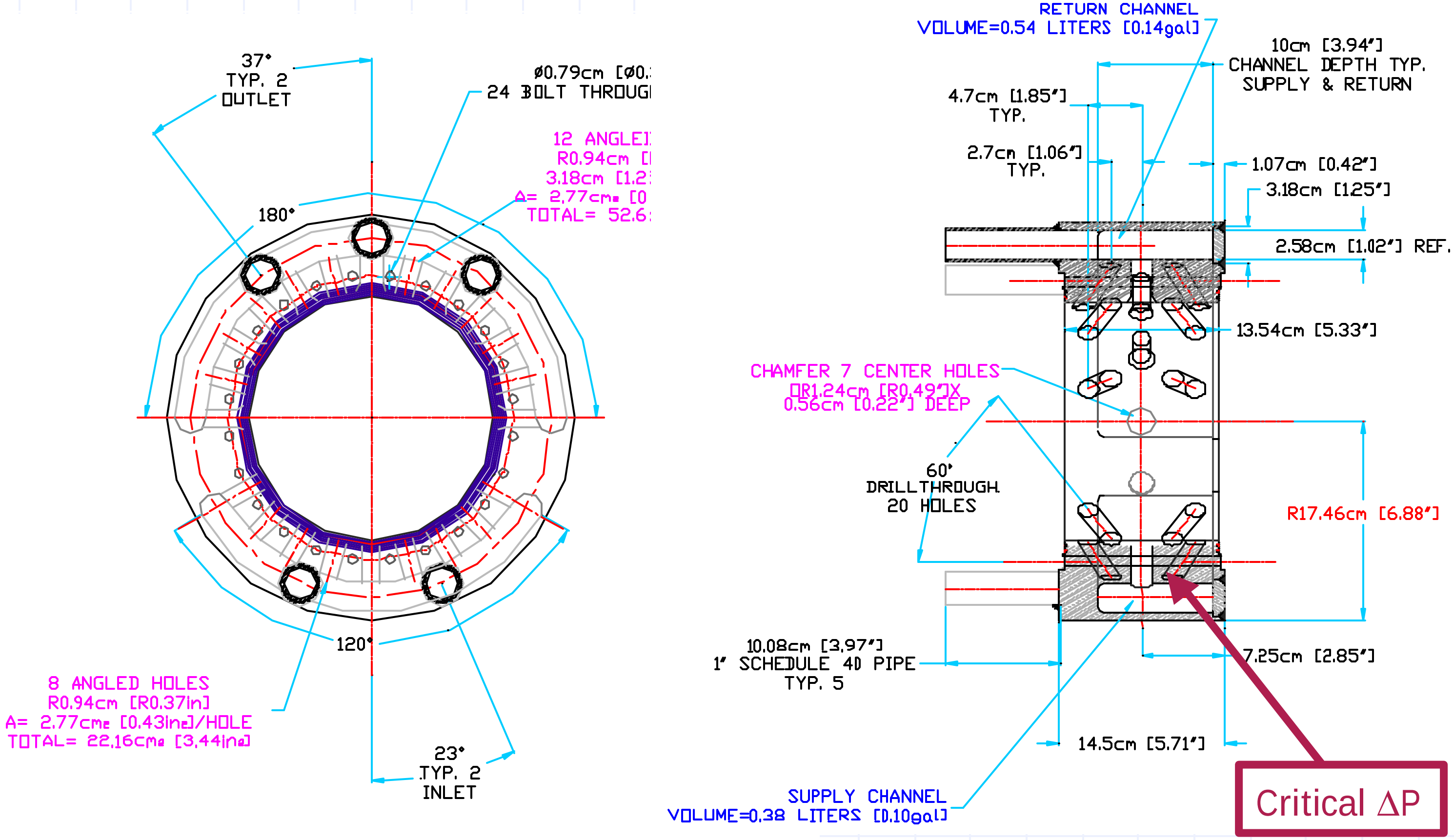
Cryo-system design



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Cryo-system design

5- Supporting system assembly

- **between the absorber and the thermal shield**
- **between the thermal shield and vacuum vessel**
- **between the vacuum vessel and magnet bore**

- **G10 and Stainless steel band**
- **Alignment**
- **No longitudinal translation**
- **No motion if quench**

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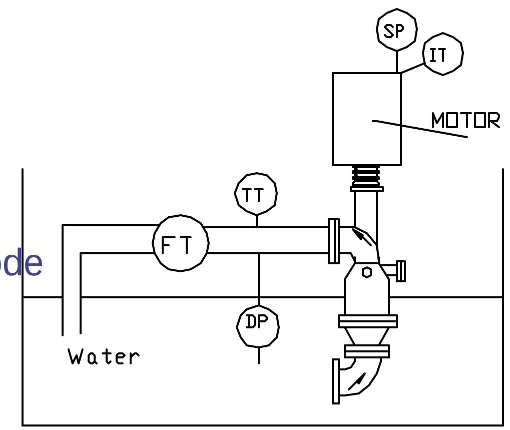
Cryo-system design – Water pump test

The motor of the pump should be mounted in the vertical position

The thermal path is more effective if flow travels from “bottom to top” in LH2 absorber

Pump test with water allow us:

1. to compare the mass-flow of water in direct and reverse mode
2. to measure the mass flow for different water temperature
3. to measure the mass flow for different motor current
4. to measure the Pressure drop across the pump
5. to correlate the measurement of the water flow and the motor speed
6. to determine the flow rate to use in the Mucool experiment



Reverse mode

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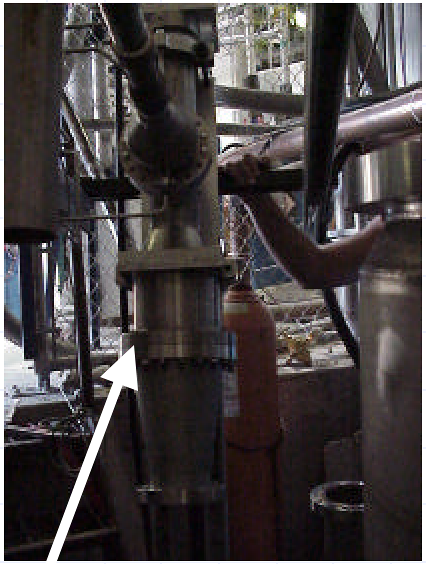
Cryo-system design – Water pump test



Pump and dia. reduction

Venturi flow meter

Diff. Pressure => flow

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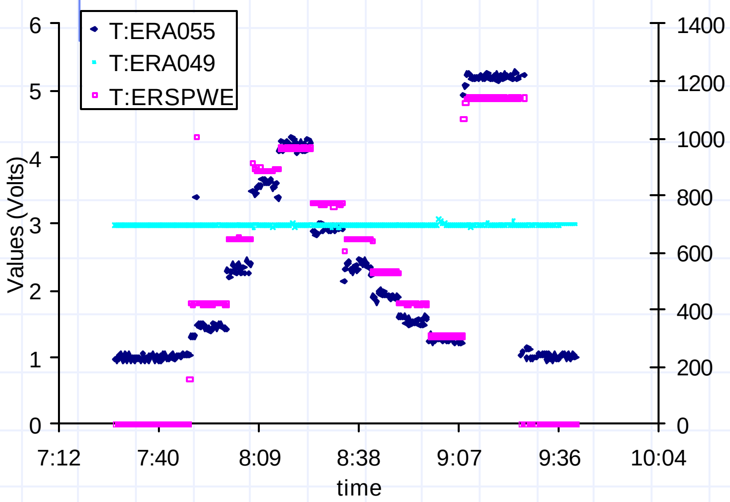
Cryo-system design – Water pump test

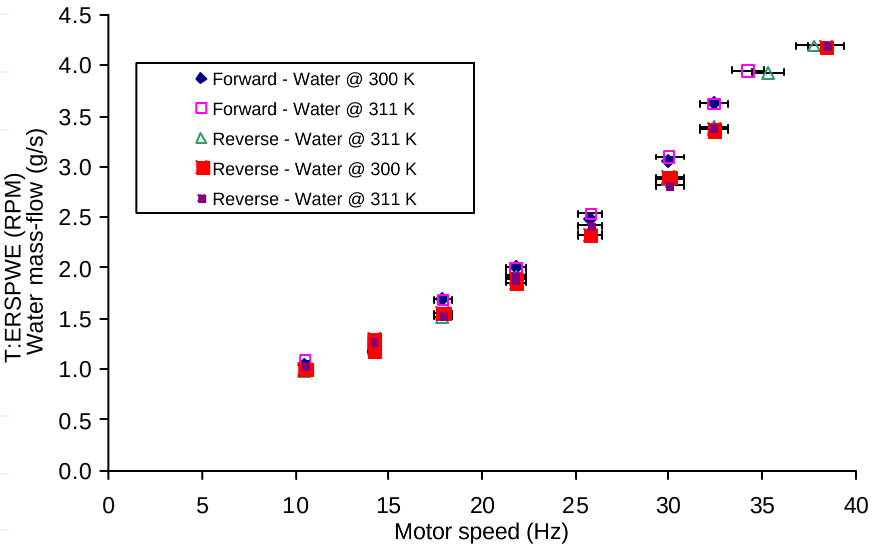
Some results: (see internal report for detail)

1. Efficiency of the pump in the reverse more is 5 % lower than in the forward mode
2. We may not be able to run to more than 450~500 g/s

Reverse mode @ RT



Comparison for 5 run tests (2 forward+3 reverse)



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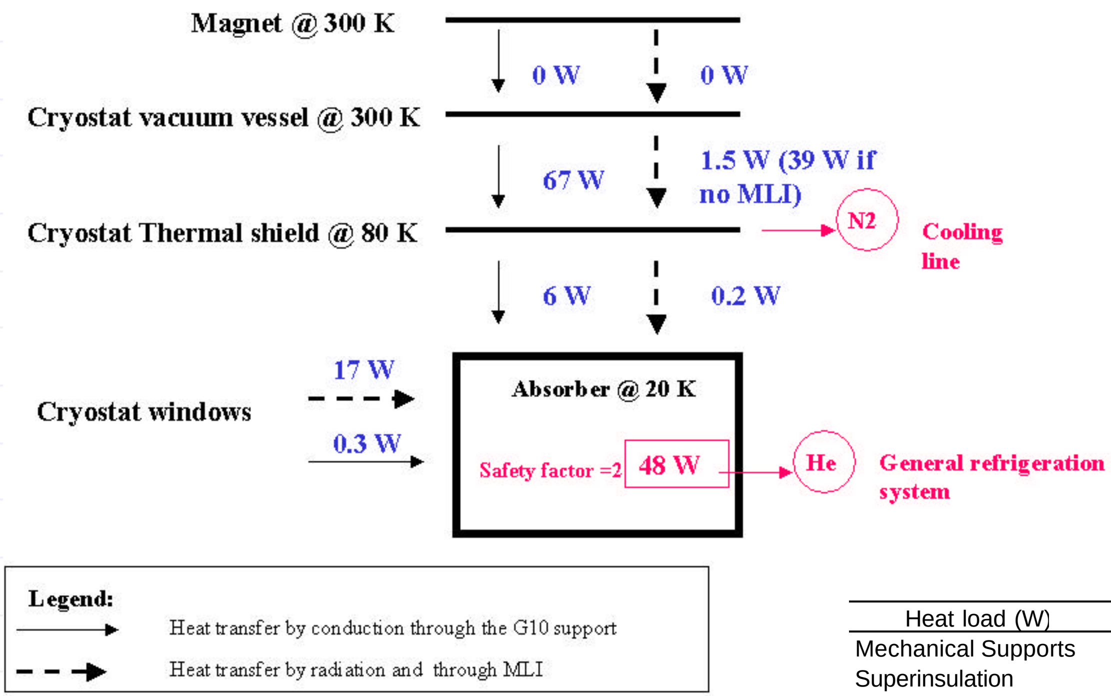
Cryo-system design-Heat transfer calculations



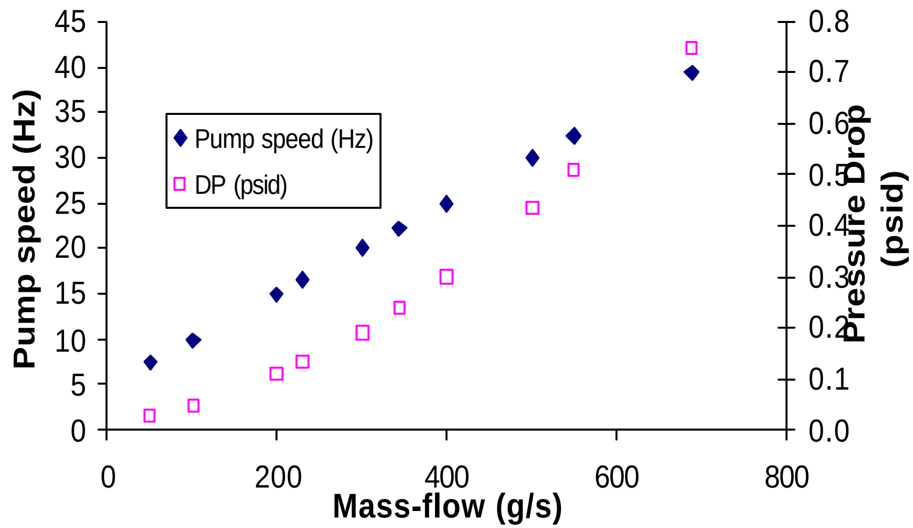
Heat load (W)	80 K	17 K
Mechanical Supports	67	6
Superinsulation	1.5	0.2
Cryostat windows	-	17
LH2 pump	-	50
Total	68.5	73.2

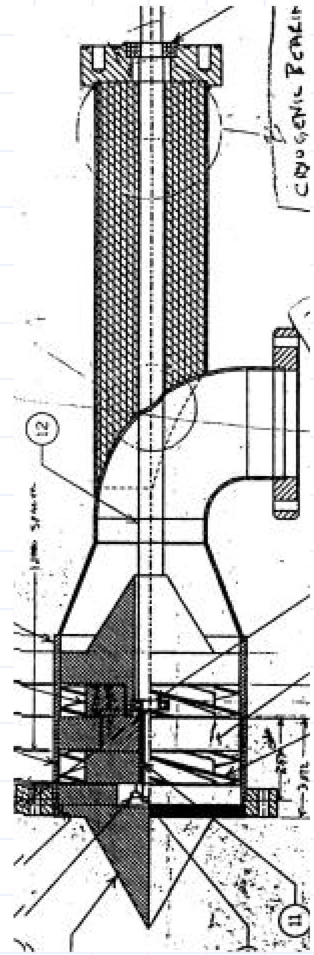
Characteristics of the SAMPLE LH_2 pump

Flow rate up to 0.55 kg/s

ΔP = 0.365 psi @ m=450 g/s
ΔP = 0.032 psi @ m=63 g/s

Design of the pump





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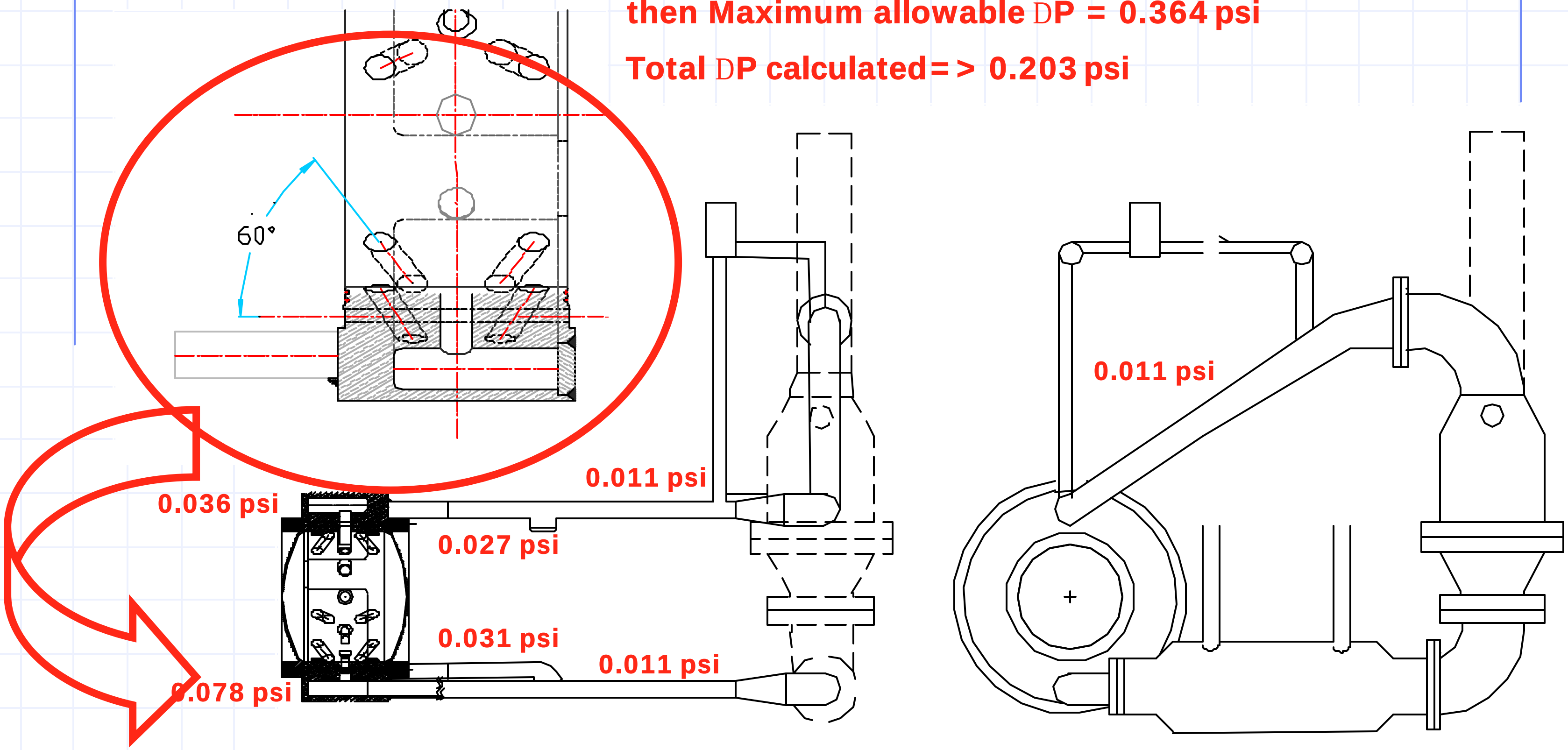
Cryo-system design- Pressure drop calculation

If m=450g/s and 32 nozzle dia. = 0.6"

then Maximum allowable DP = 0.364 psi

Total DP calculated=> 0.203 psi



Will a velocity at the nozzle equal to 2.5 m/s be enough for ionization cooling?

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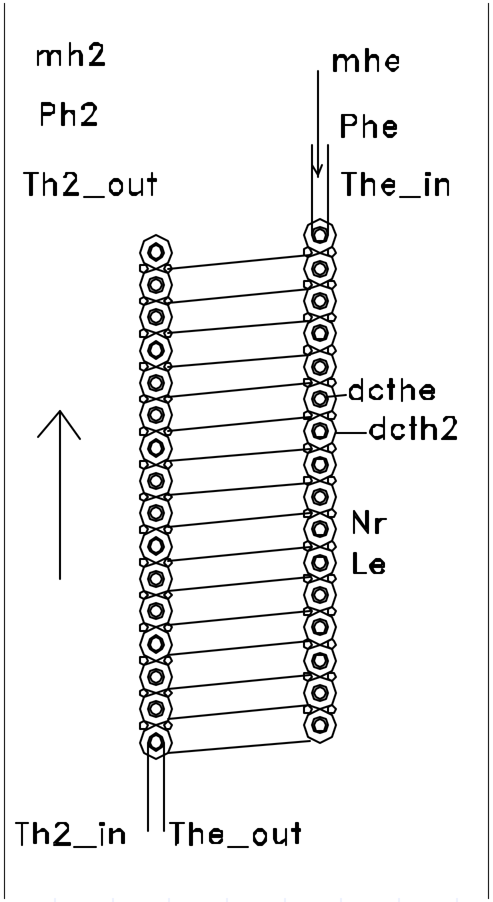
Cryo-system design – HX design

Note- assumption:

- **Heat exchange: Helium/LH2 counter-current flow**
- **Reduction diameter = 2 "**
- **ID coil = 0.555 inch, L=6.6 m, t = 0.035 inch**

Parameters

- **Power to extract from the absorber:Q=500 W**
- **Temperature in/out He loop:Thein=14 K Theout=17.5 K**
- **Temperature in/out H2 loop:Th2in=18 K Th2out=17 K**
- **Pressure He/H2 :Phe=0.2 MPa Ph2=0.121 MPa**
- **Mass-flow He/H2 :mhe=27 g/s mh2=63 g/s**
- **Helium properties (Hepak)**



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To meet the standard

Instrumentation choice: explosion proof or intrinsically safe system

Fermilab: " Guidelines for the Design, Fabrication, Testing, Installation and Operation of LH2 Targets – 20 May 1997" by Del Allspach et al.

II C: LH2 loop

- Relief system and sizing

II D: Vacuum system:

- Relief system and sizing
- Venting piping pressure drop
- What if analysis

II F: External piping and valve

II H: Absorber support stands

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To meet the standard

Pressure relief valve – LH_2 : II C 4 a (iii)

- Relief pressure (10 psig or 25 psid)
- Sized for max. heat flux produced by air condensed on the **LH_2** loop at 1 atm.

2 valves ACGO **=> 0.502 in^2**
ASME code **Redundant**
Capacity = 52 g/s

Pressure relief valve – Insulation vacuum : II D 3

- MAWP (15 psig internal)
- Capable of limiting the internal pressure in vacuum vessel to less than 15 psig following the absorber rupture (deposition of 25 liter in the vacuum space)
- Vapor evaluation q= 20 W/cm2
- Take into account DP connection piping and entrance/exit losses

3 parallel plates (FNAL design) **=> 2”**
ASME code **Redundant**
Capacity = 197 g/s

Relief system must be flow tested

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To meet the standard

Conclusions

Design related

- Thermo-hydraulic parameters are still to be validated before we fix the heat exchanger design
  - Hydrogen mass flow requested (physics/manifold design)
  - Helium cooling power (refrigeration at 14 K)

    see Alex M. talk

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Cryo-system design

Issues

- The 2HP motor (LH2 pump driver) needs to be cooled, and needs a Nitrogen barrier environment.
  - Pumping between the 2HP motor and the LH2 pump to prevent freezing N2 when pumping=> Pressure stabilization in LH_2 loop
- LH_2 buffer functionality
- Heater bonded to the HX outer shell
  - time constant for diffusion through wall
- Radiation hardness: to withstand 0.11mS/hr (11mrem/hr)
- Quench will induce some forces to the supporting system